

Drought Under Global Warming

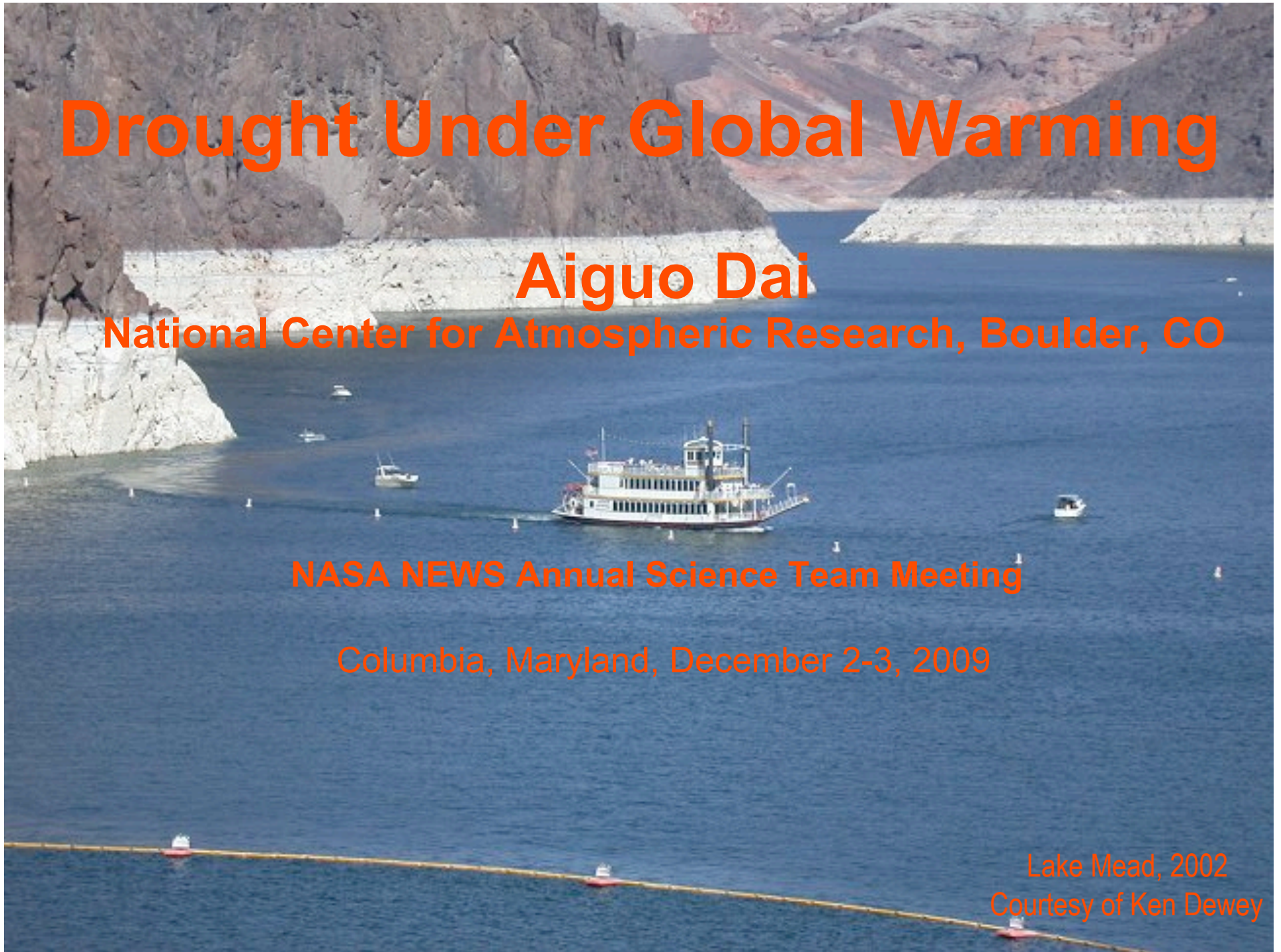
Aiguo Dai

National Center for Atmospheric Research, Boulder, CO

NASA NEWS Annual Science Team Meeting

Columbia, Maryland, December 2-3, 2009

Lake Mead, 2002
Courtesy of Ken Dewey



Outline of the Talk

- A brief introduction on drought
- Drought in the U.S.
- African drought
- Global drought during the 20th century
- Global drought in the 21th century

What is Drought?

- **Drought** is a recurring climate event over land characterized by a lack of precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid regions.
- Three common types of drought:
 - **Meteorological drought** is a period of months to years with below normal precipitation. It precedes and causes the other types of droughts.
 - **Agricultural drought** is a period with dry soils that results from a lack of precipitation and leads to reduced crop production and plant growth.
 - **Hydrological drought** develops when streamflow and water storages in aquifers, lakes or reservoirs fall below long-term mean levels.

Why drought research?

- Drought is among the most-damaging natural disasters

*The **average annual costs** of the common disasters in the US (source: NDMC):*

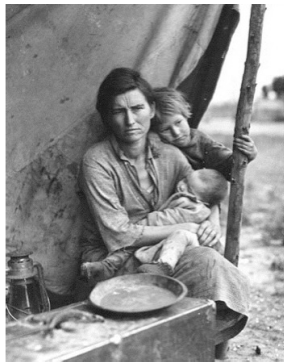
Drought: \$6–8 billion
Flood: \$2.41 billion
Hurricane: \$1.2–4.8 billion

*Which **specific events** had the highest costs?*

Drought: the 1988–89 drought cost an estimated \$39–40 billion
Flood: floods in 1993 cost an estimated \$15–27.6 billion
Hurricane: Hurricane Andrew (1993) cost \$25–33.1 billion

- Drought may become more severe and widespread under global warming.

The Dust Bowl drought of the 1930s ...

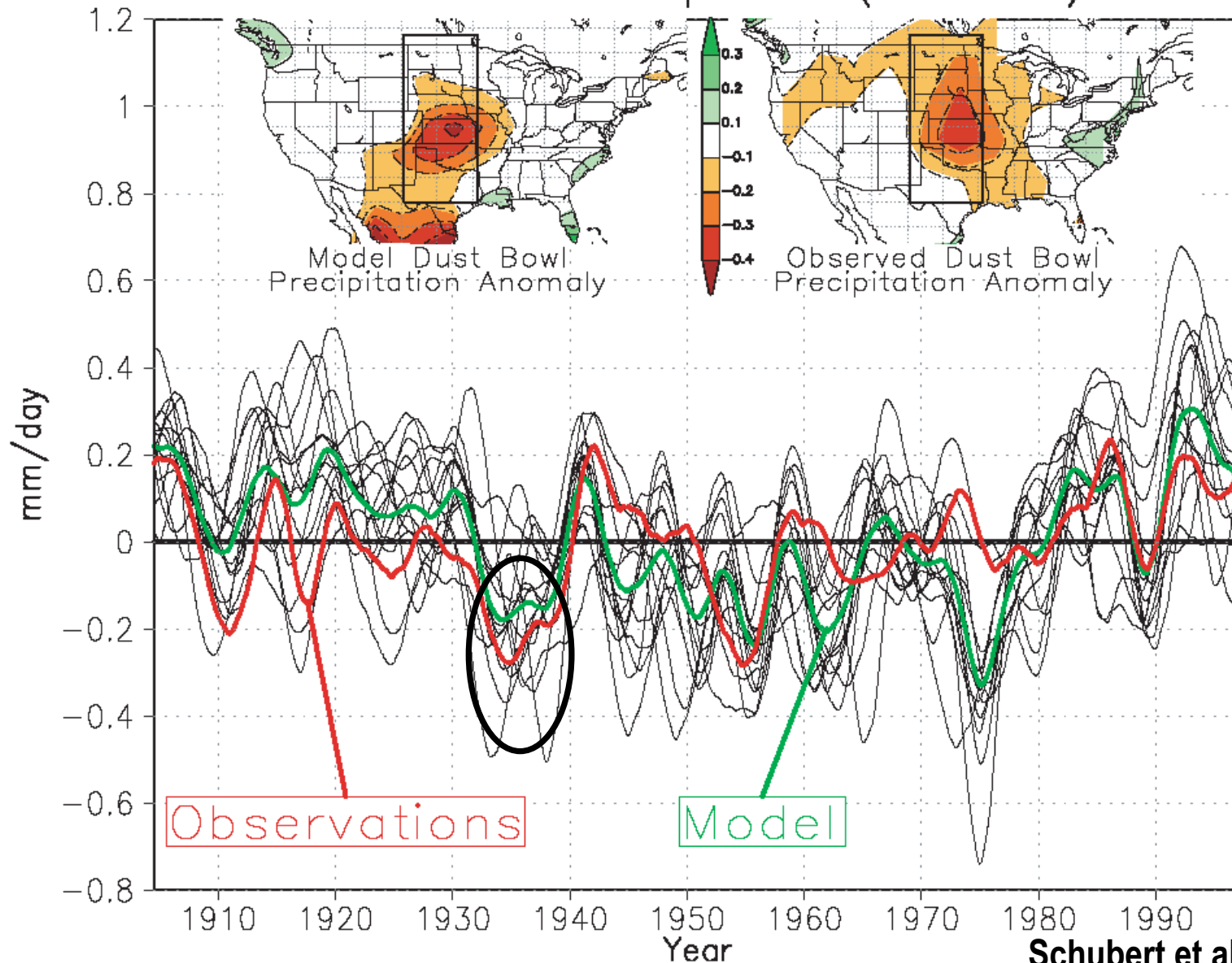


Model-Simulated U.S. Precipitation



NCAR

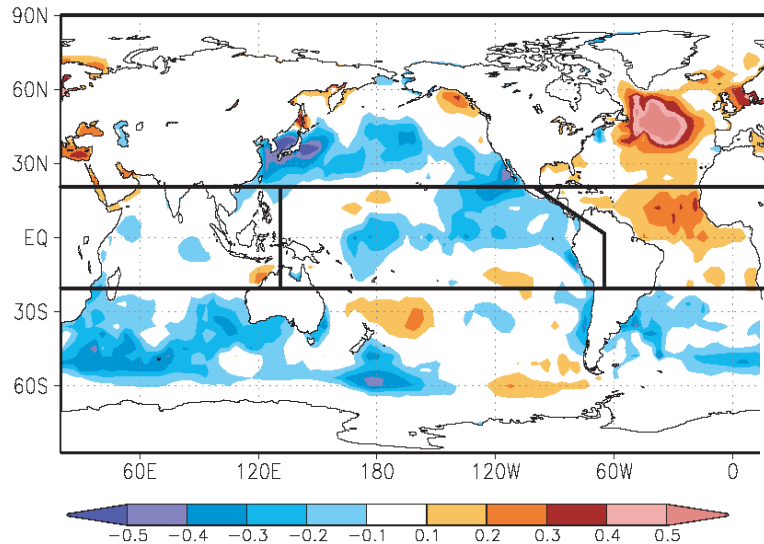
Great Plains Precipitation (Low Pass)



Schubert et al.'04, *Science*

Model Studies on U.S. Droughts

1932–1938 composite SST

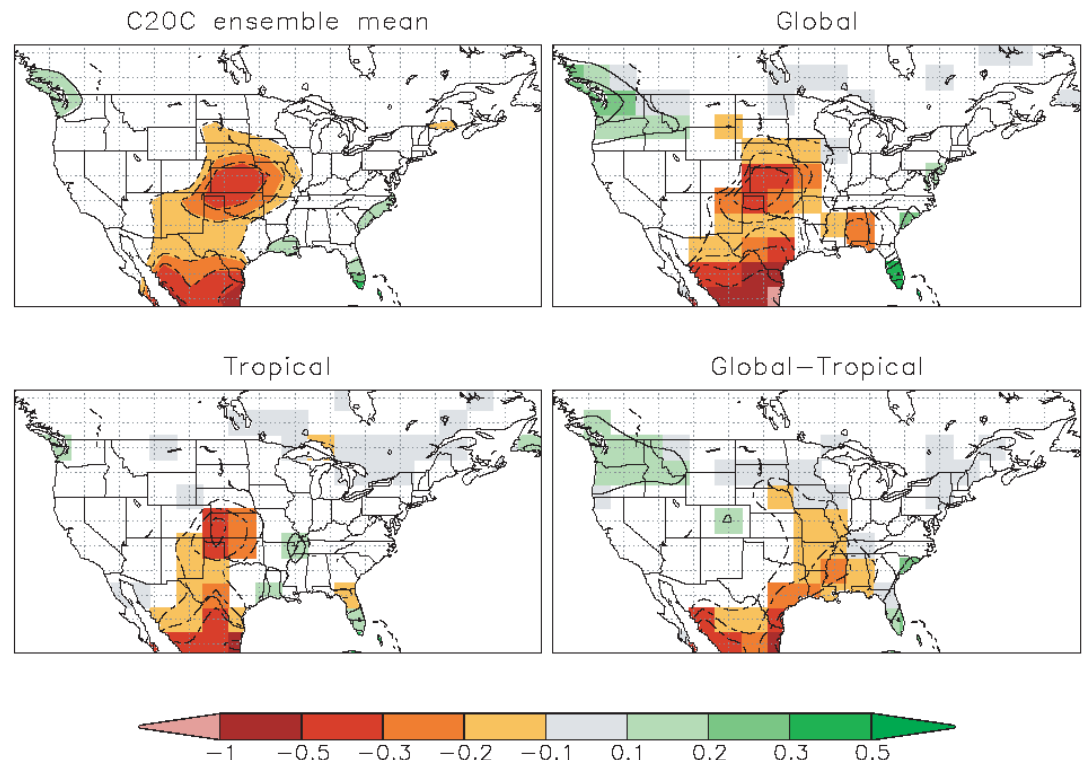


Tropical SST contributed the most!

Experiments by R. Seager also confirmed this using NCAR CCM3.

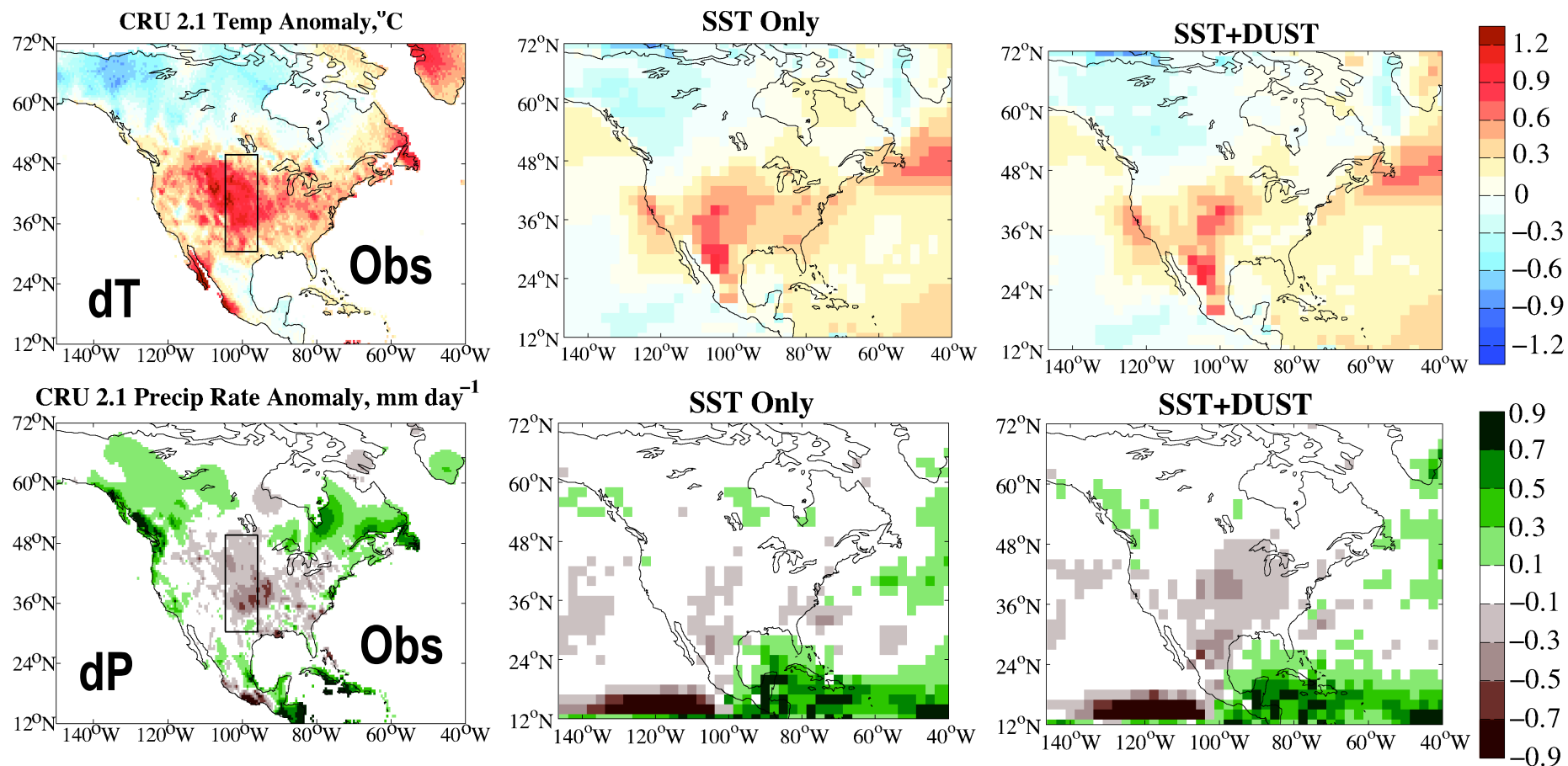
Some groups are working on decadal drought prediction using predicted tropical SSTs.

1932–1938 Composite Precipitation



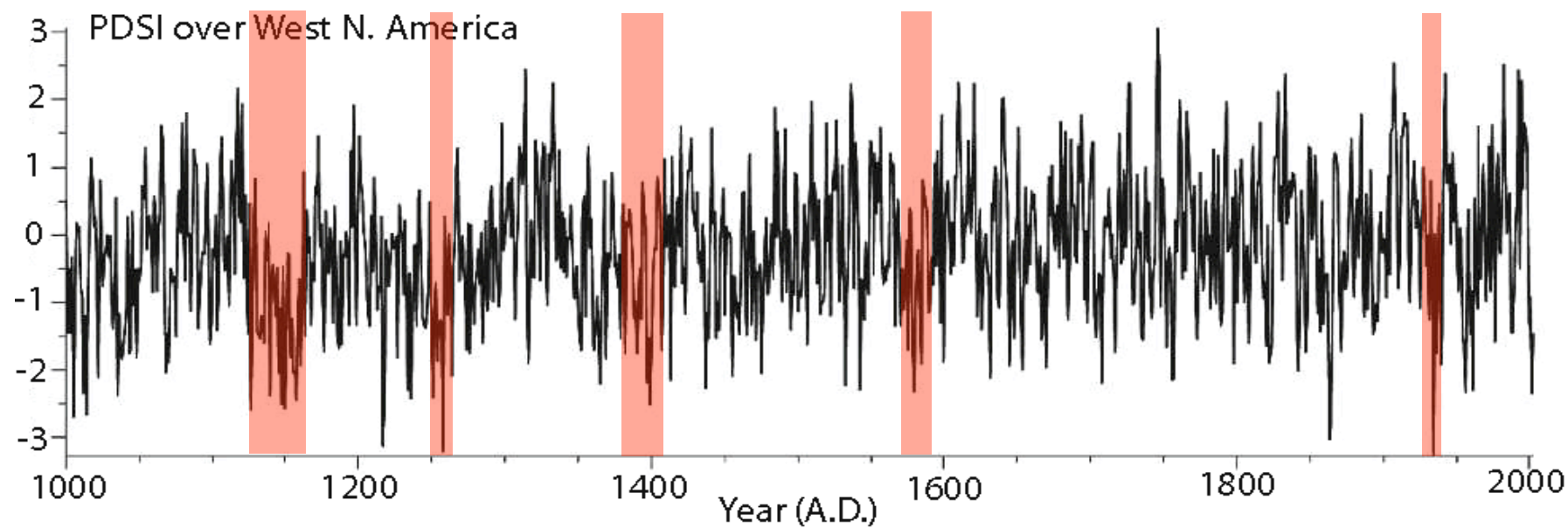
Schubert et al.'04, Science

Aerosols Amplify the Dust Bowl Drought



(Cook et al. 2009)

Historical Perspective for N. American Droughts



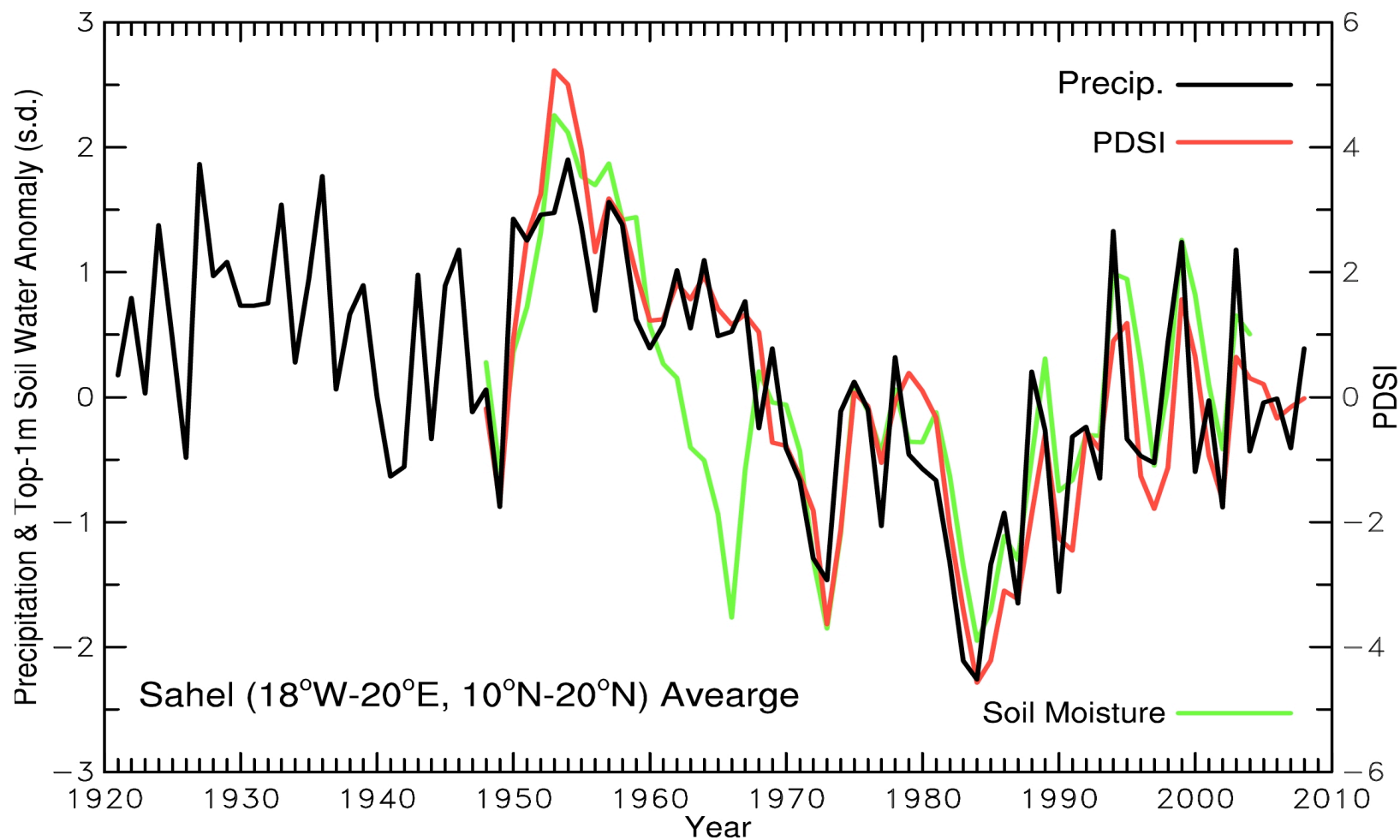
**Tree-ring re-constructed PDSI over West N. America (25-50°N, 95-125°W)
from 1000-2000 (from Herweijer et al. 2007, JC)**

The Sahel Drought



Photo: C.J. Tucker

Sahel Annual Rainfall and PDSI: 1920-2008

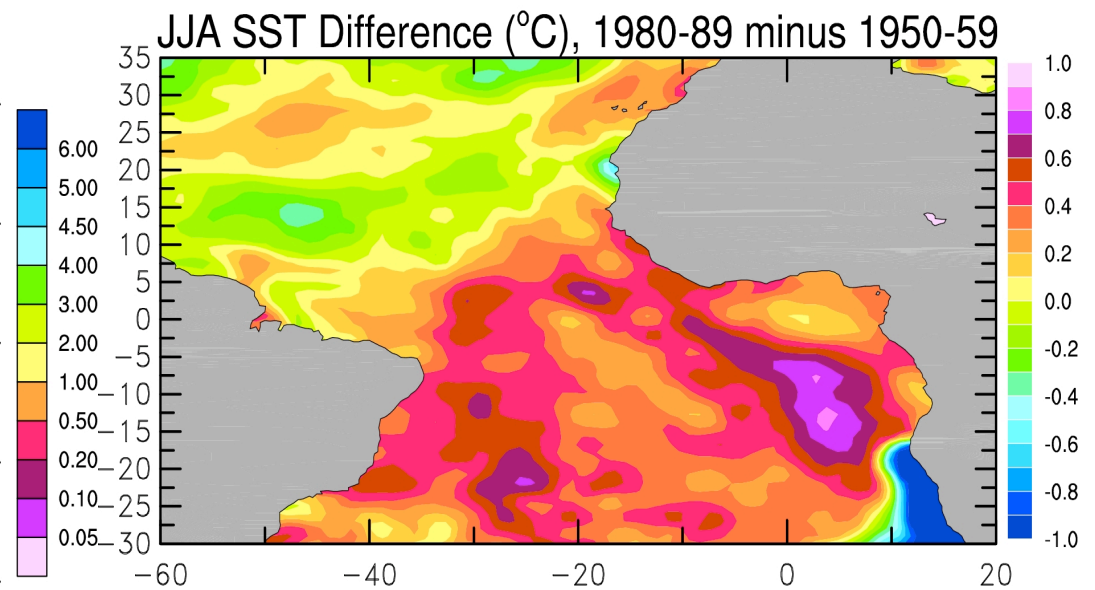
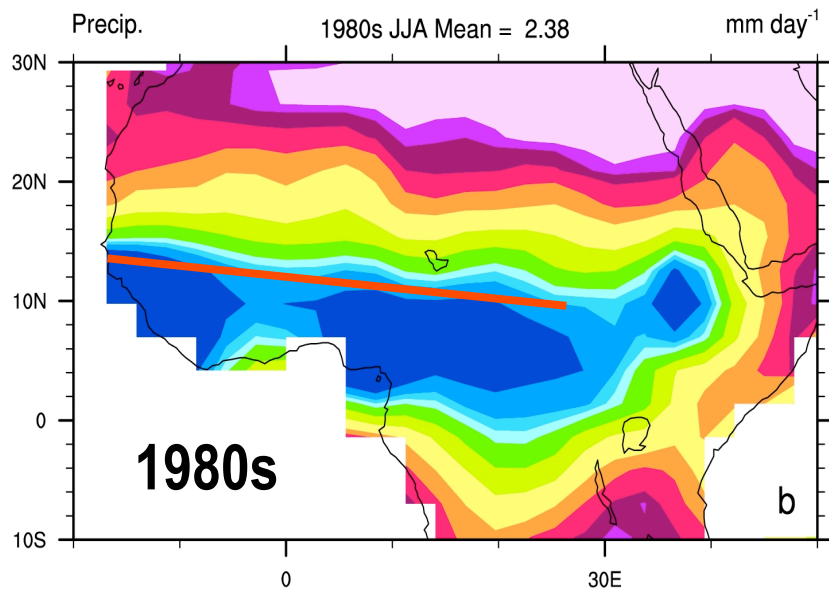
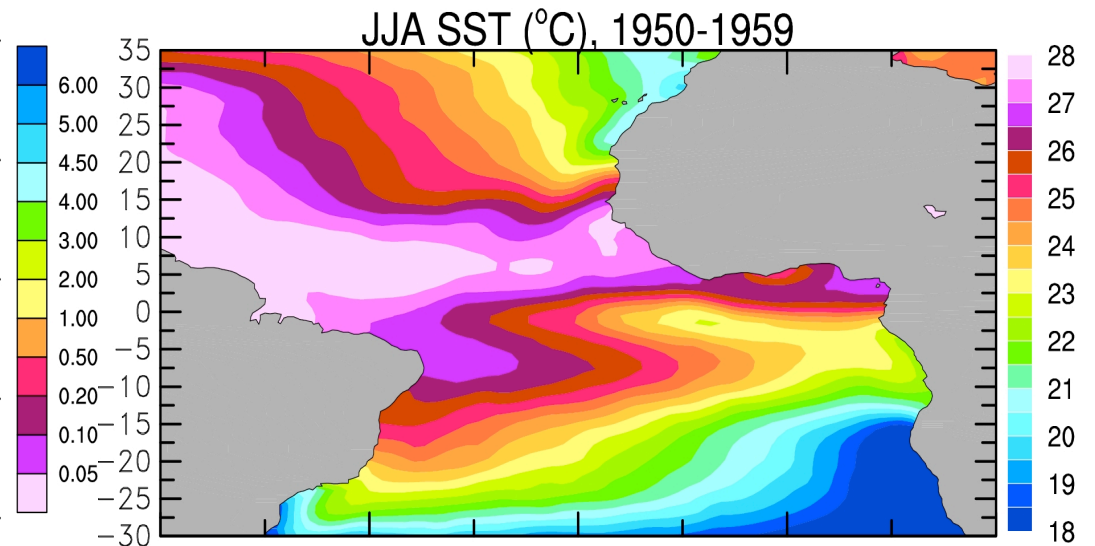
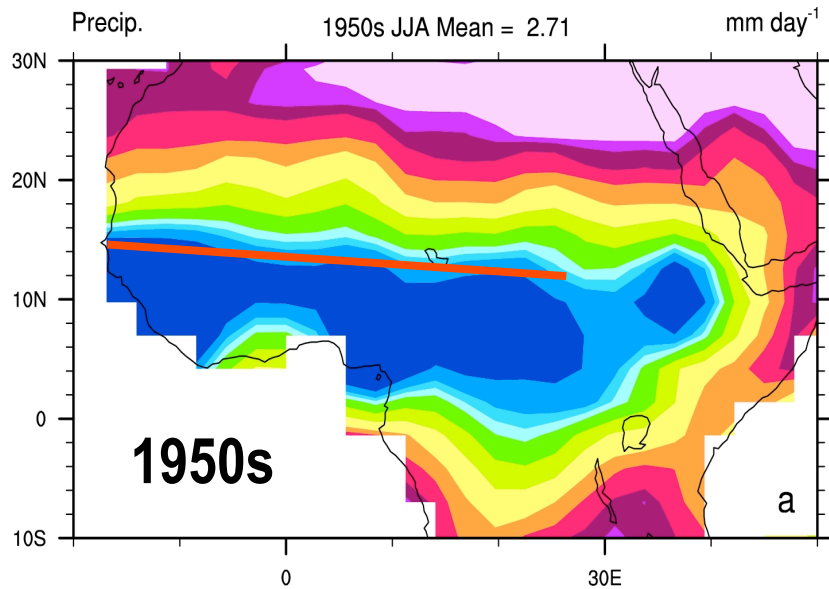


Update to Dai et al. (2004)

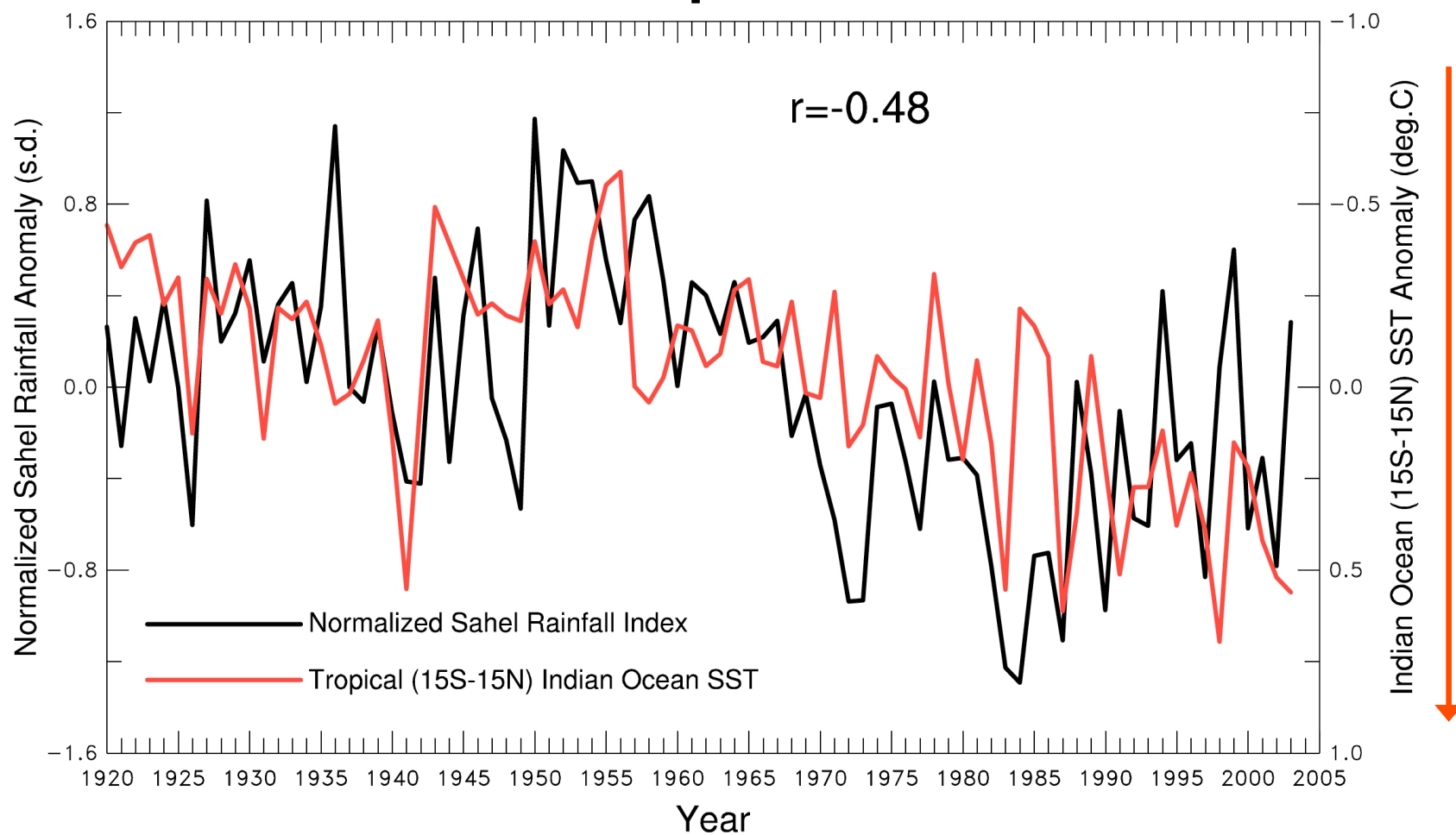
Sahel JJA Rainfall Pattern: 1950s vs. 1980s



NCAR

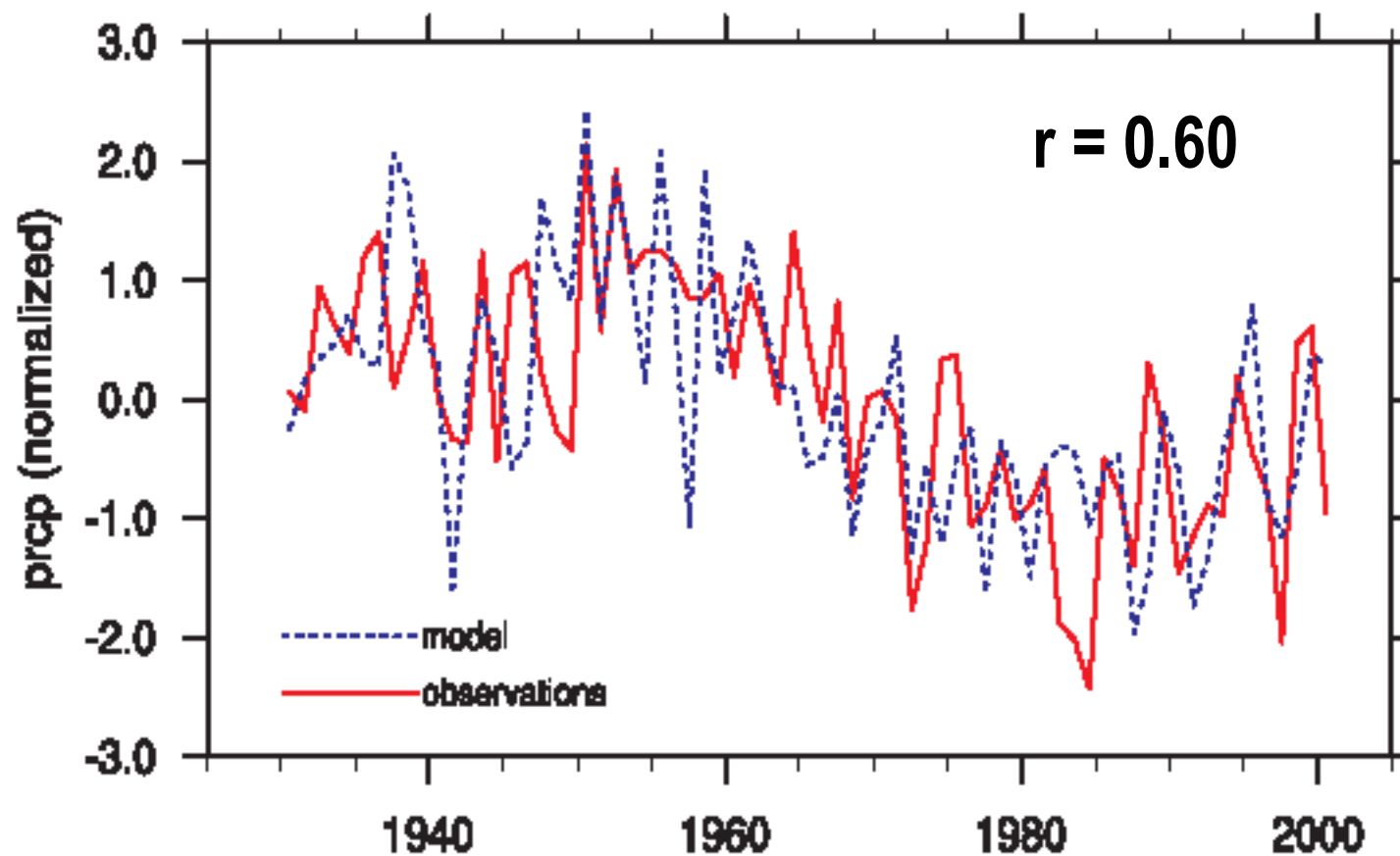


Sahel Rainfall vs. Tropical Indian Ocean SST



NASA AGCM Forced by Observed Global SST

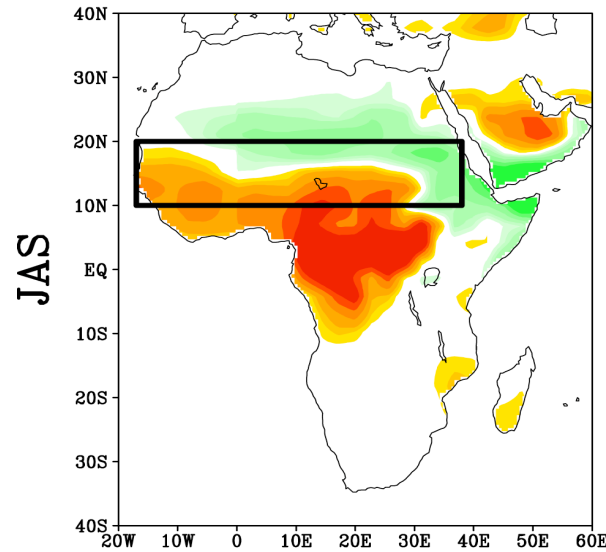
Sahel precipitation - July-September 1930-2000



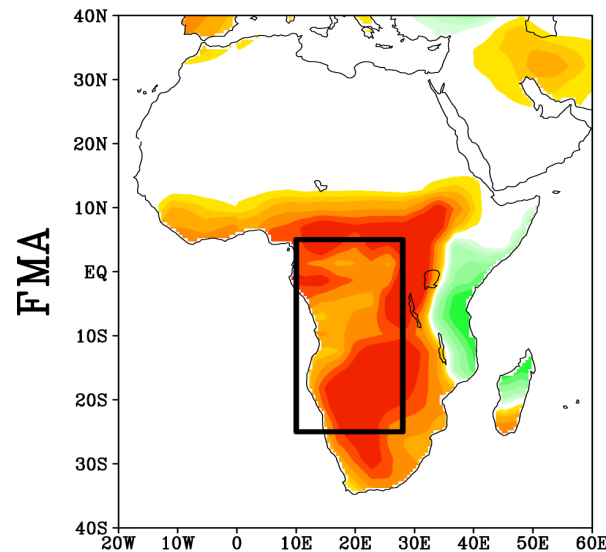
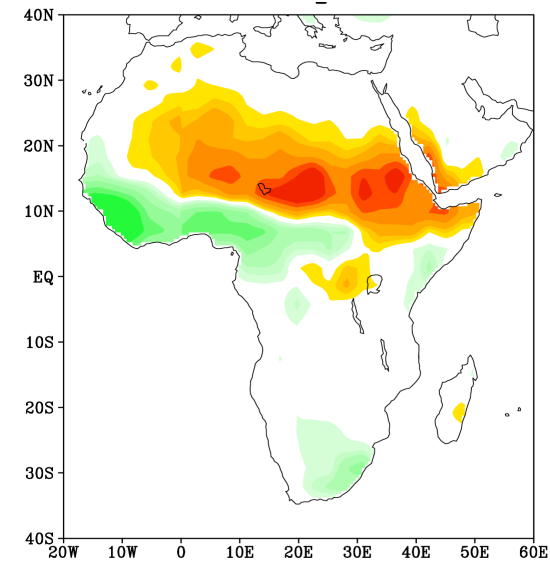
(Giannini et al. 2003)

1°C Indian Ocean SST Warming Obsvd Atlantic SST Only

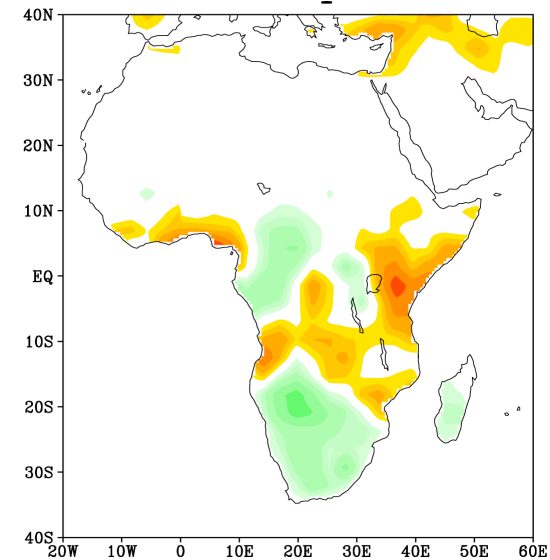
NCAR



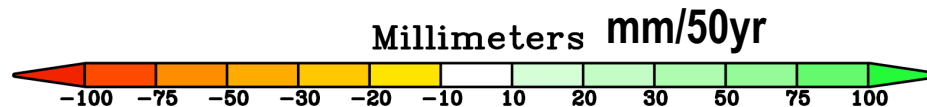
JAS Precip Change



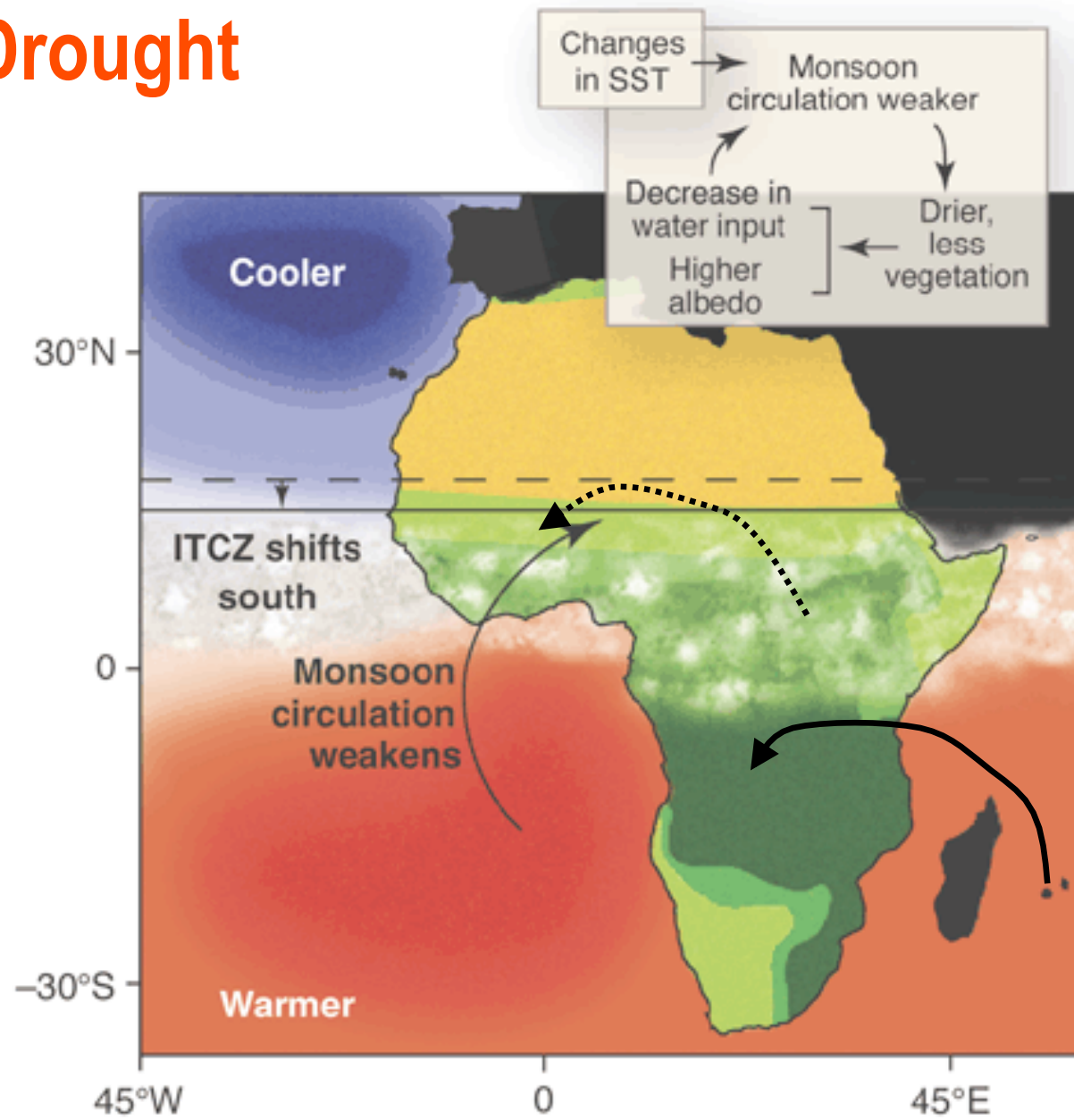
FMA Precip Change



Hoerling et al. 2006

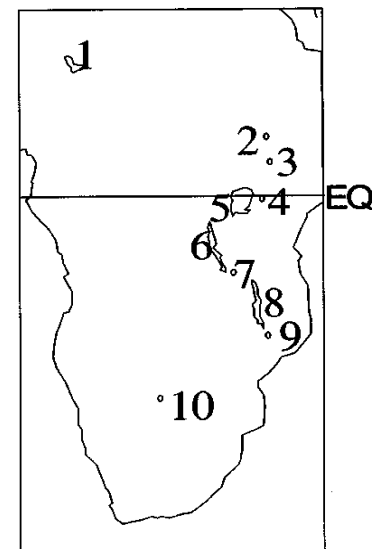
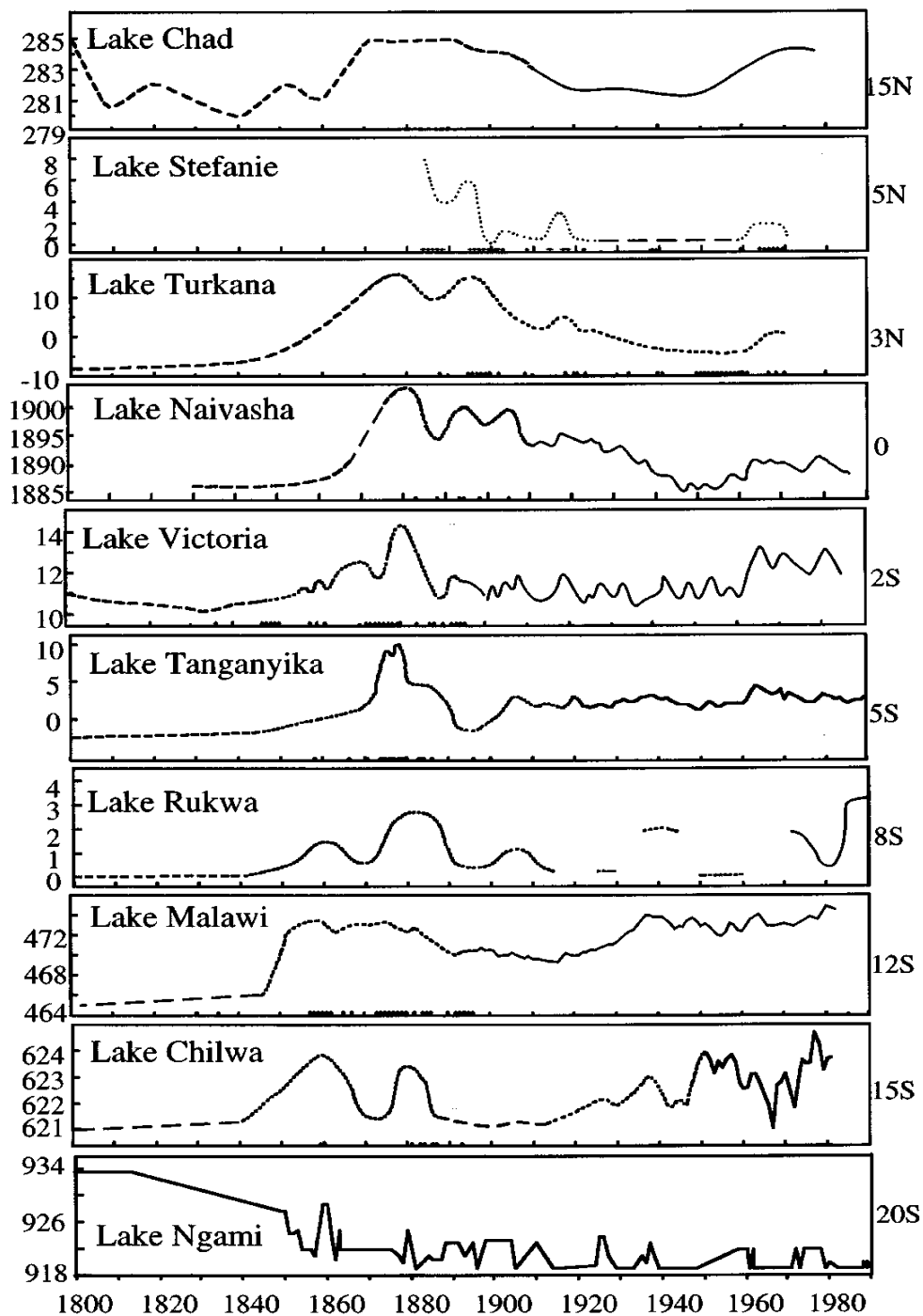


Sahel Drought



Modified from Zeng (2003)

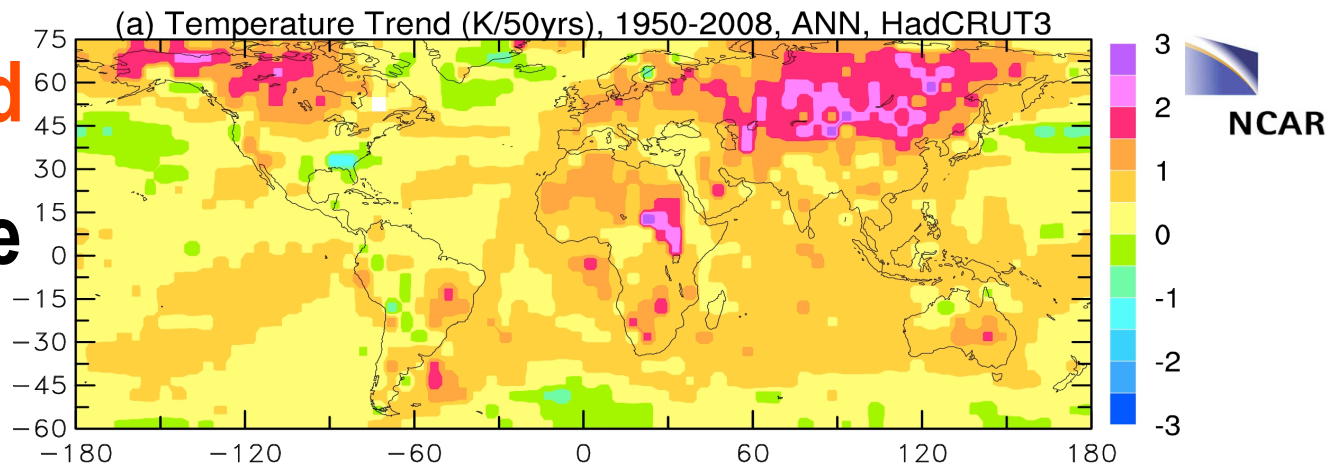
Lake Level



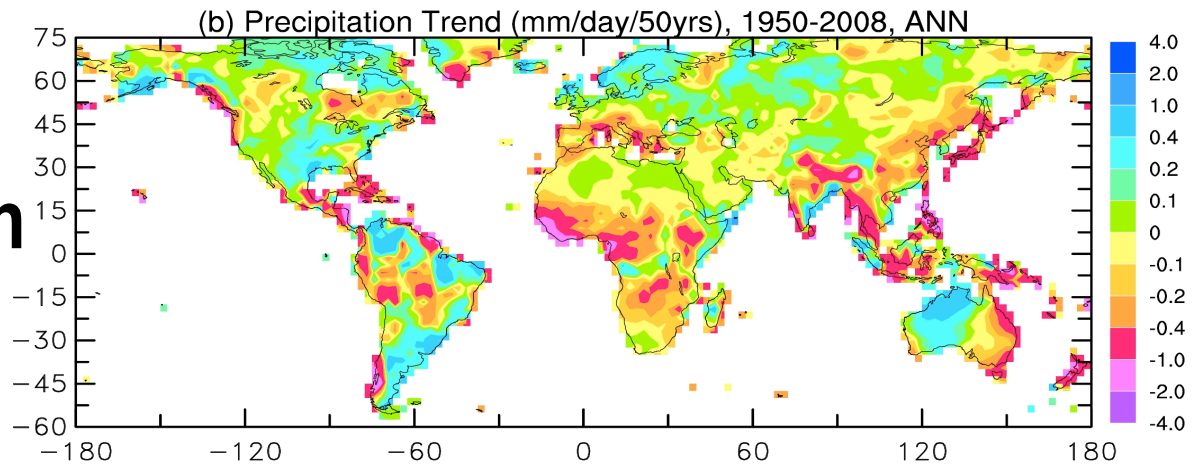
- 1) Chad
- 2) Stefanie
- 3) Turkana
- 4) Naivasha
- 5) Victoria
- 6) Tanganyika
- 7) Rukwa
- 8) Malawi
- 9) Chilwa
- 10) Ngami

1950-2008 Trend

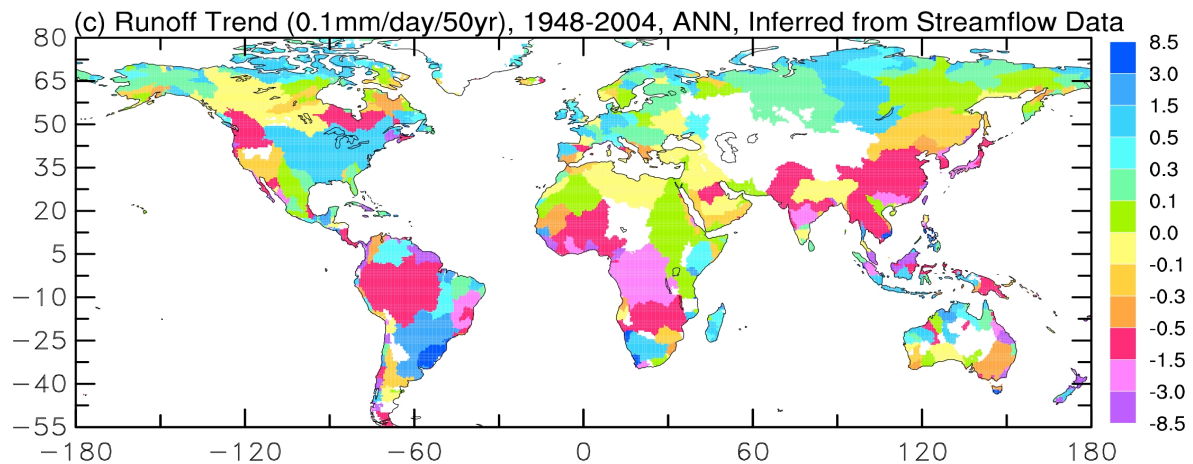
Temperature



Precipitation



Runoff



Processes May Lead to Increased Drying over Land under Global Warming

- Increased long-wave radiative heating provides additional energy for surface evaporation;
- Higher air temperatures increase atmospheric demand for water vapor; and
- Larger warming over land than over ocean leads to larger increases in potential evaporation over land than ocean, which may in turn lead to lower RH and thus higher water stress over land.

Palmer Drought Severity Index (PDSI)

for assessing changes in global aridity



- PDSI is a measure of **meteorological drought** widely used in the U.S.;
- PDSI is computed using a bucket-type land surface model using observed precipitation and surface air temperature;
- PDSI is correlated with observed soil moisture content and streamflow; and
- PE is computed using both Thornthwaite and Penman-Montieth methods.

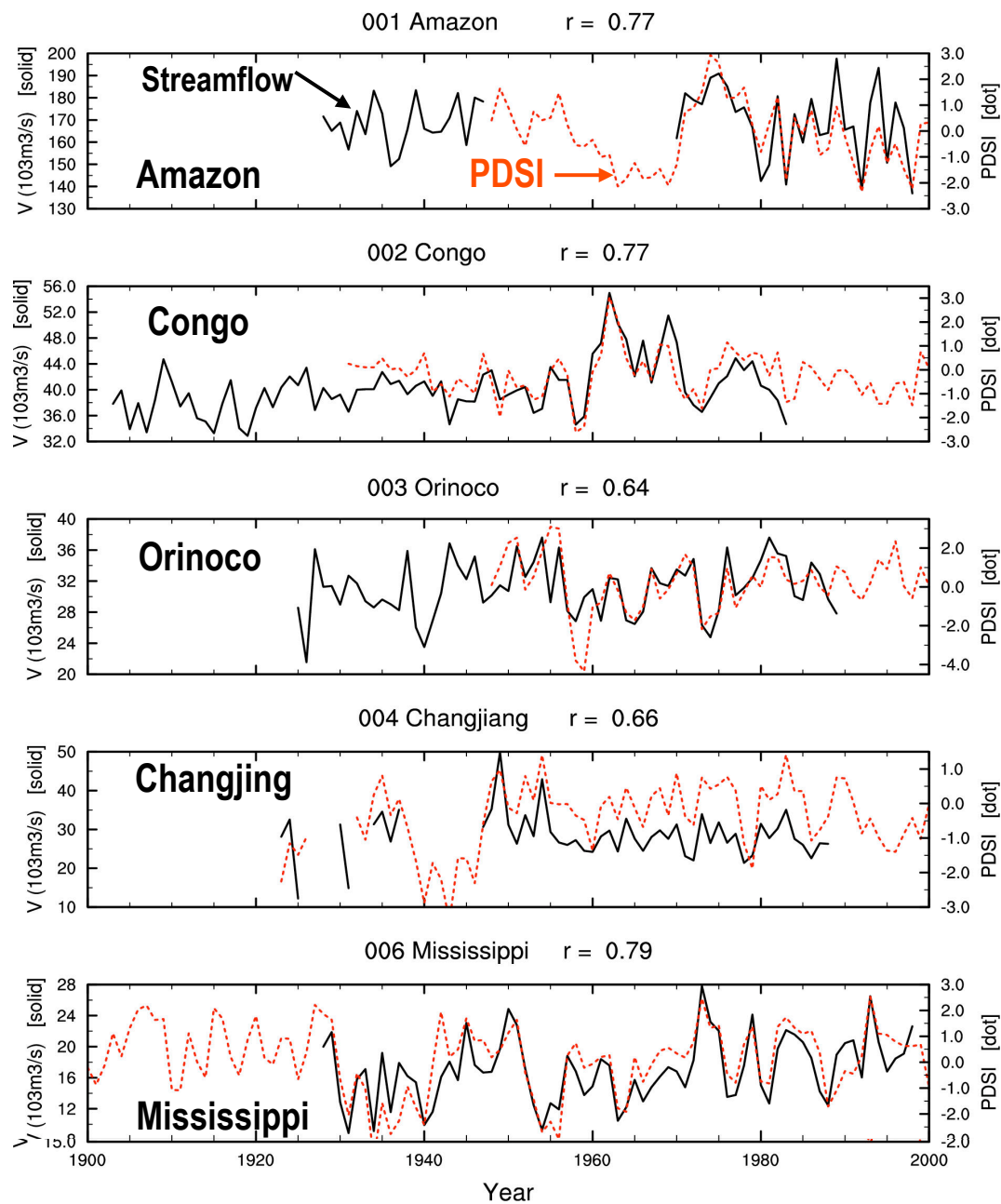
Land Model-Simulated Soil Moisture



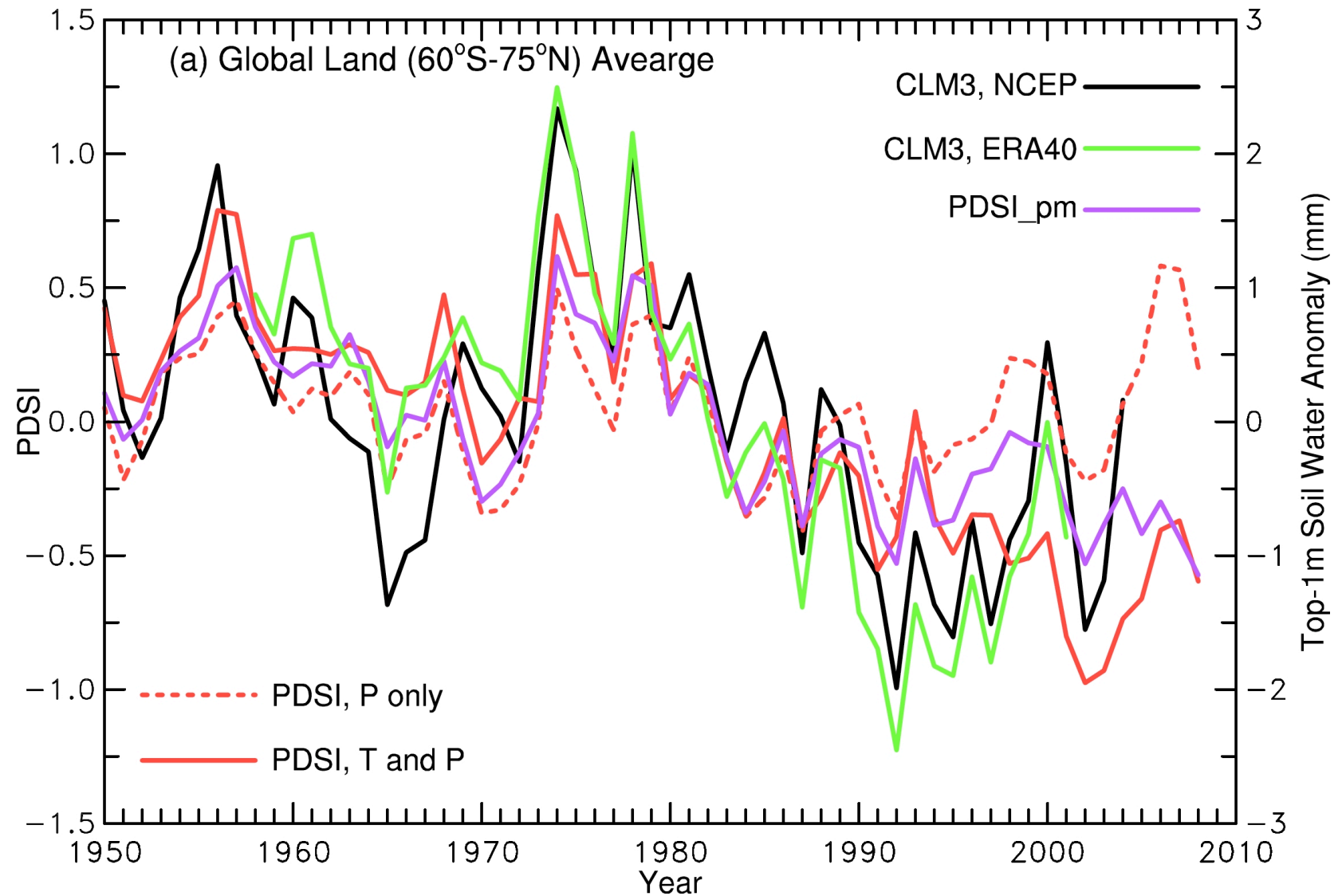
for assessing changes in global aridity

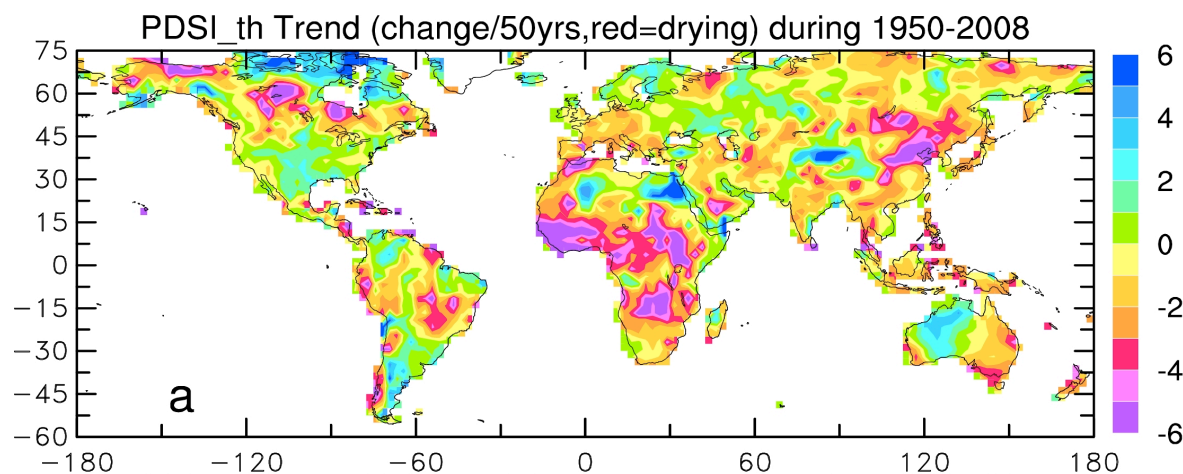
- Model: the Community Land Model V.3 (CLM3);
- Forcing data: Observed monthly temperature, precipitation, and cloud cover were used to adjust the NCEP and ERA40 reanalysis data (Qian et al. 2006);
- CLM3-simulated soil moisture is correlated with available observations;
- CLM3-simulated streamflow is correlated with observations (Dai et al. 2009);
- Other groups used model-simulated soil moisture to quantify changes in drought (e.g., Sheffield and Wood 2008).

PDSI vs. Observed Streamflow



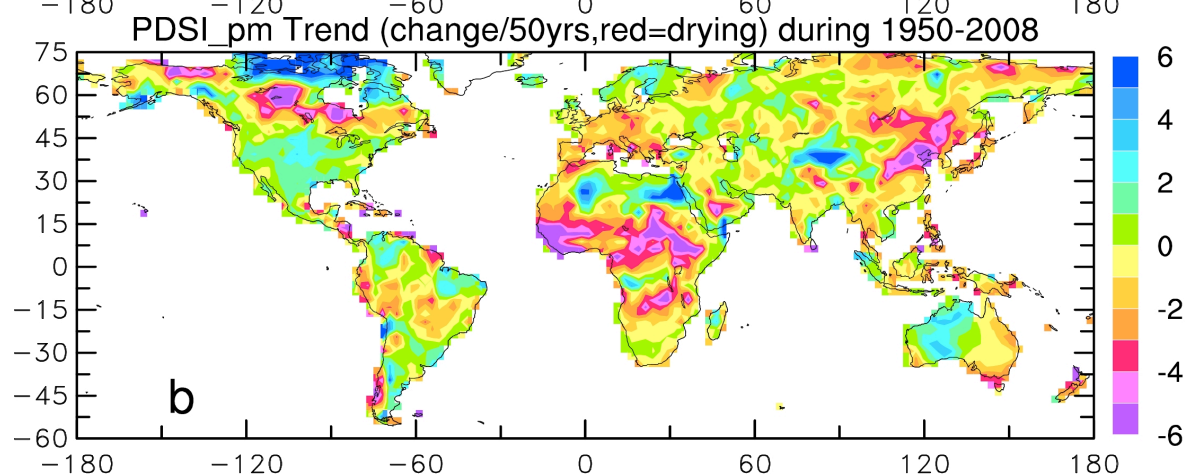
Global-mean PDSI and CLM3 Soil Water



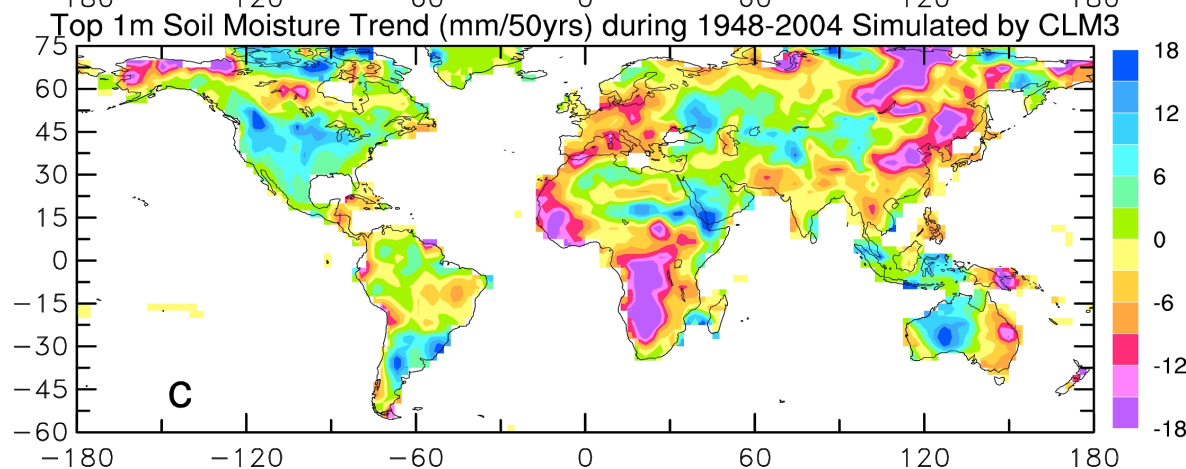


Red=Drying

PDSI_th Trend
(change/50yrs)
1950-2008

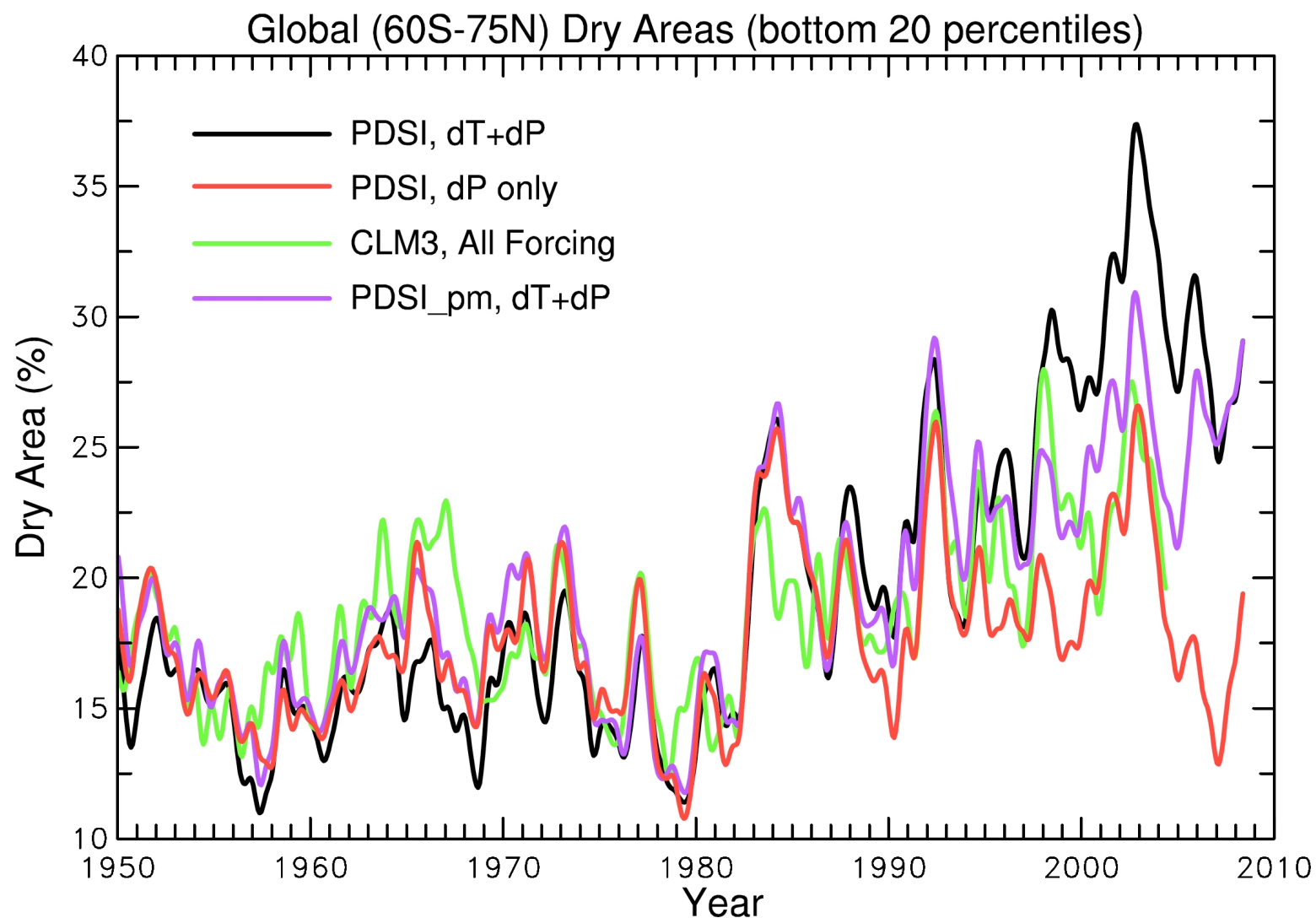


PDSI_pm Trend
(change/50yrs)



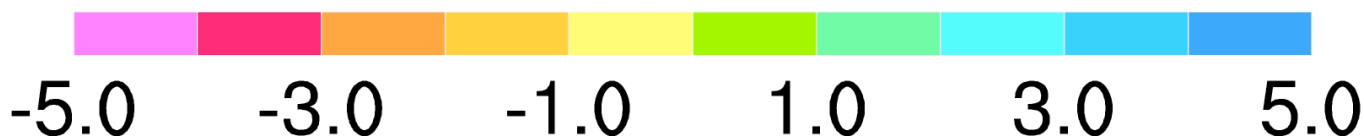
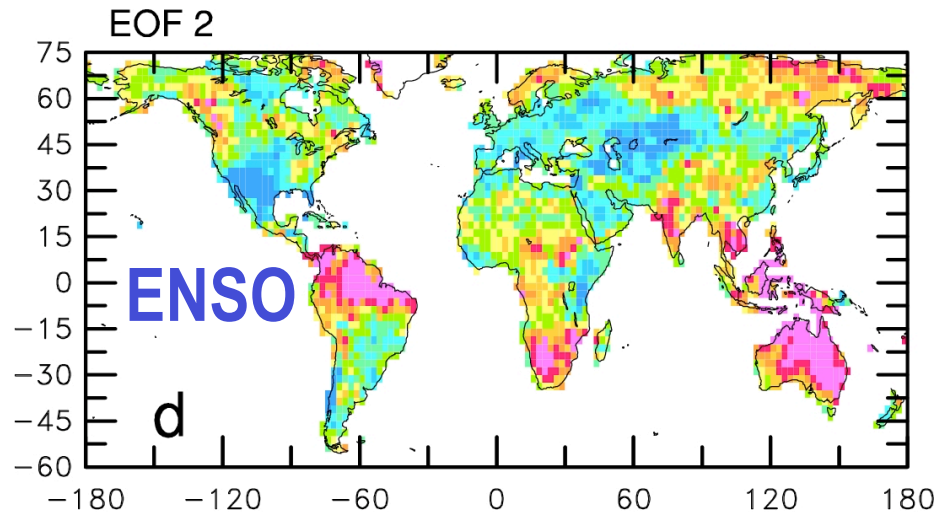
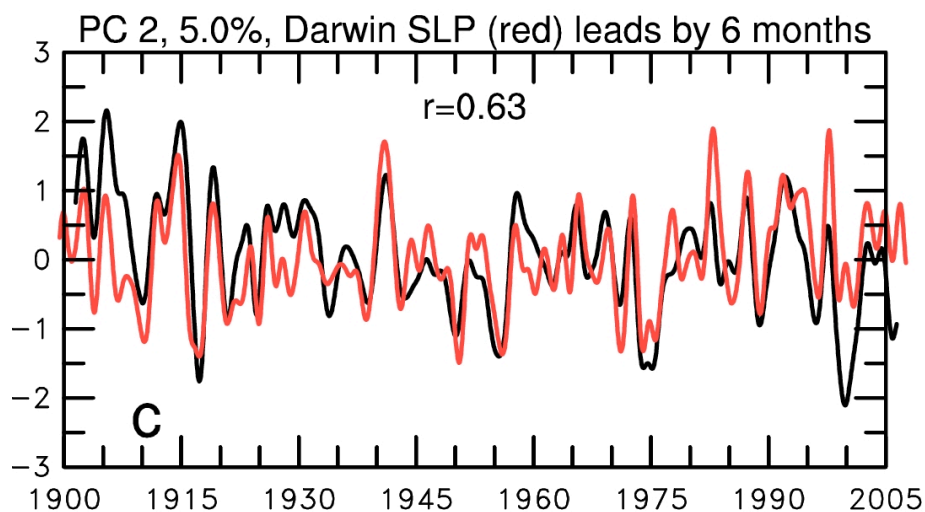
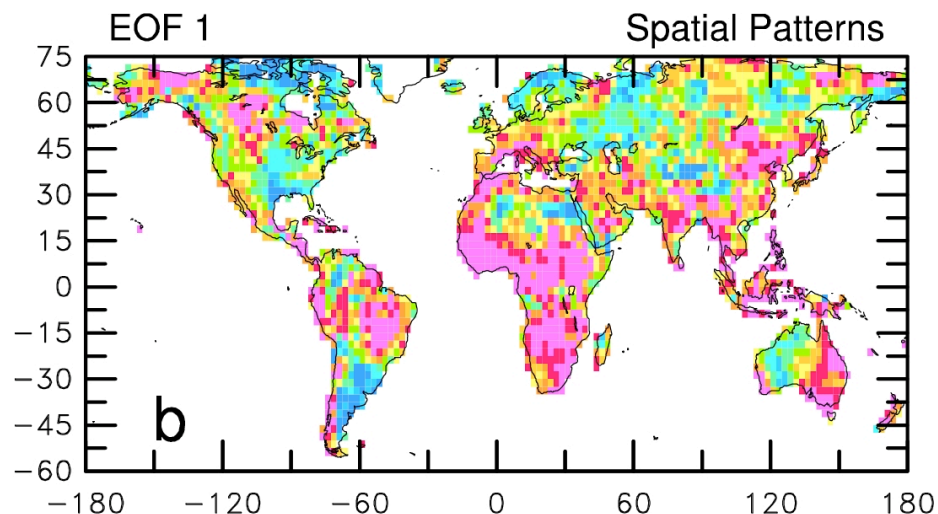
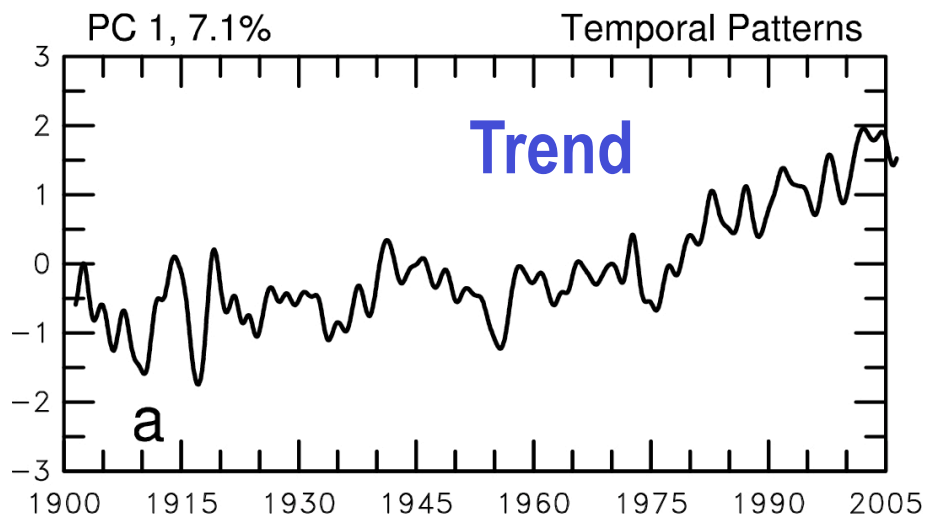
Soil Water
from CLM3
(mm/50yrs)

% Dry Area over Global (60S-75N) Land



(update to Dai et al. 2004)

Leading Modes in Global PDSI: 1900-2008



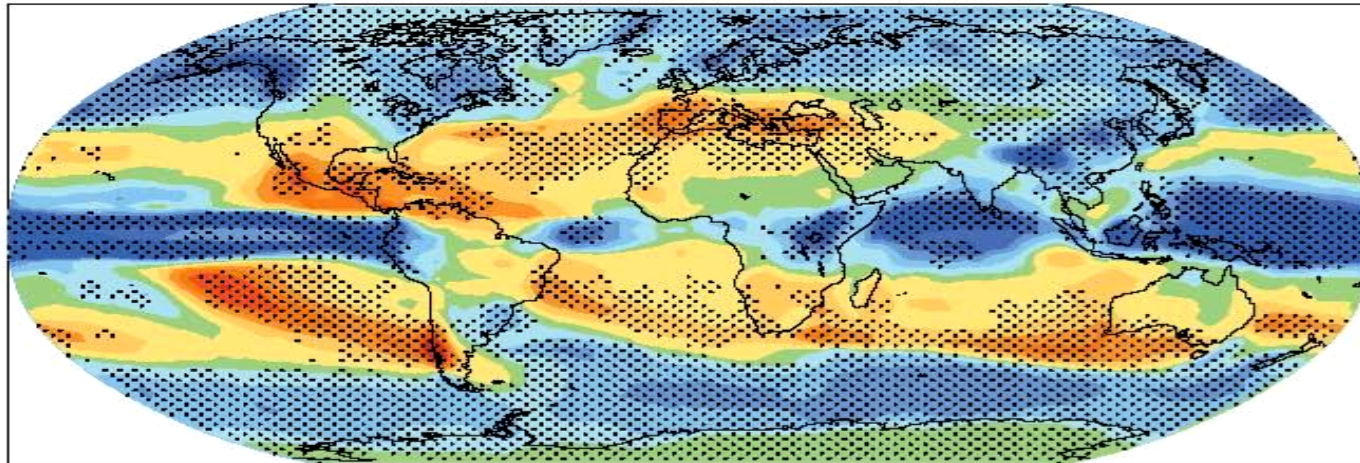
How Would Drought Change In the 21st Century?

- It will greatly depend on future tropical SSTs, and
- Precipitation patterns in the GHG-induced warmer climate.
- Current climate models have large uncertainties in simulating changes in both tropical SST and regional precipitation.

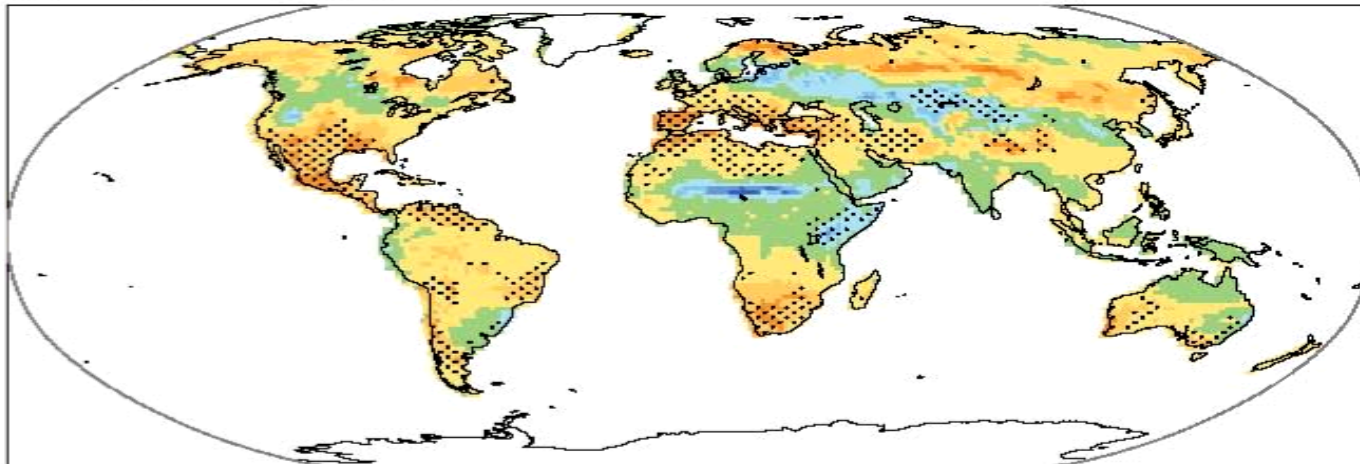
IPCC AR4 Models, 2080-99 minus 1980-99



a) Precipitation



b) Soil moisture



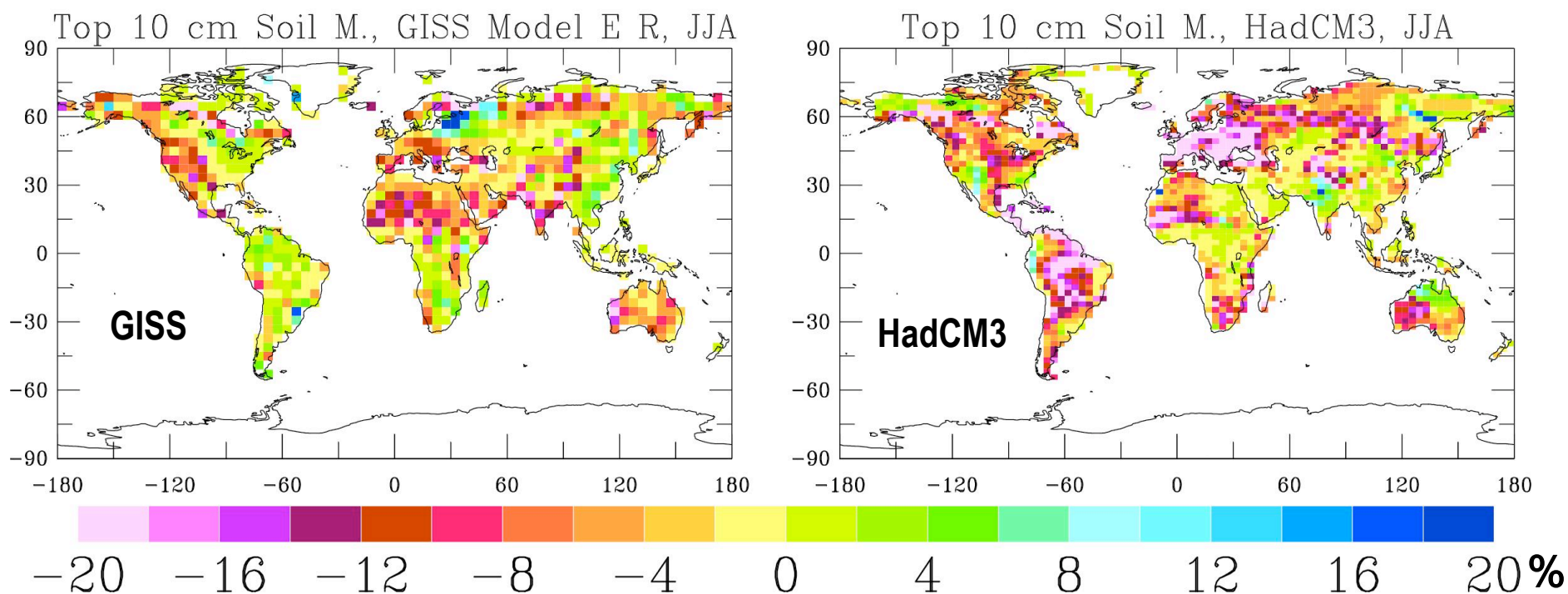
(IPCC 2007)



NCAR

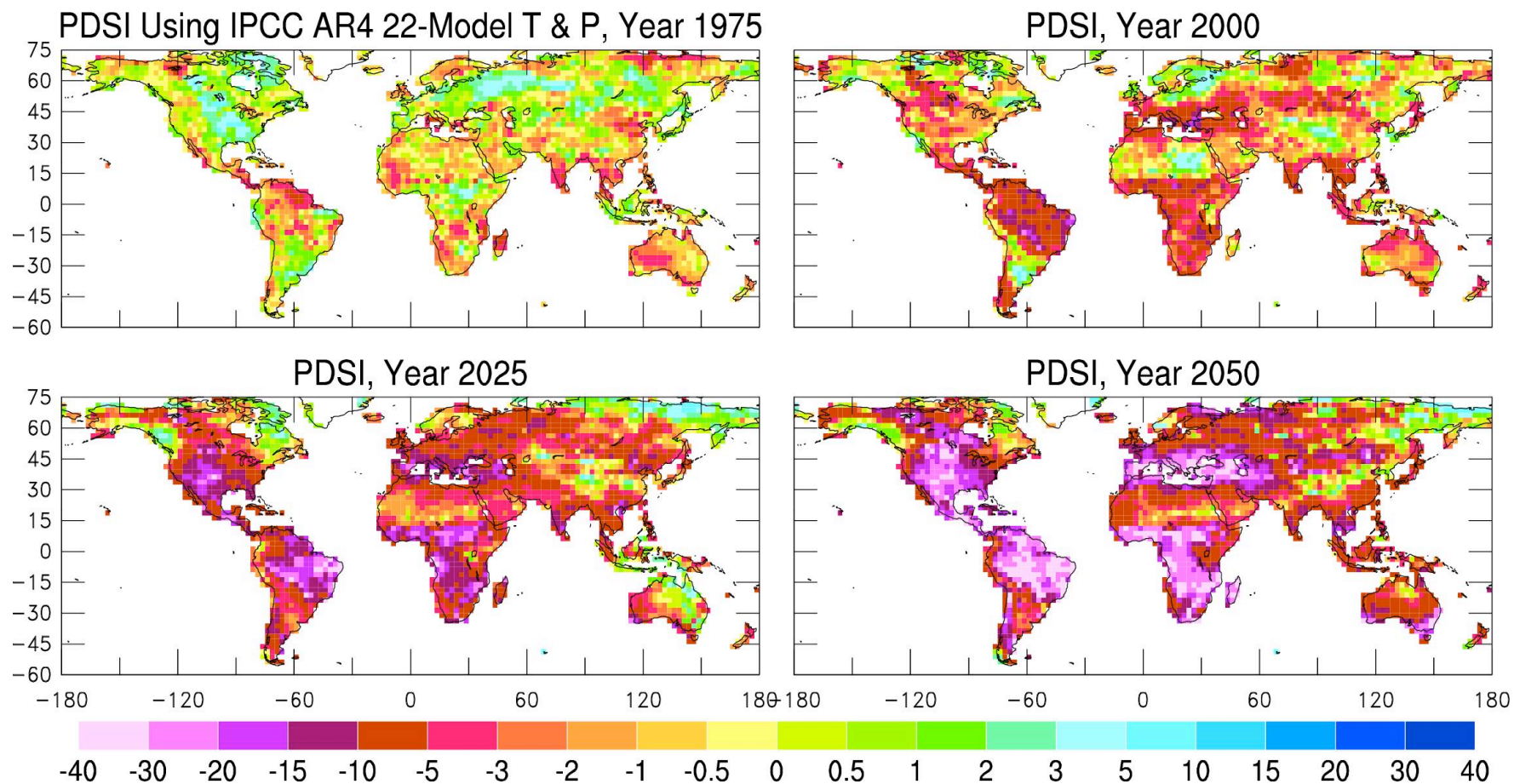
Projected Soil Moisture Changes (%) by Coupled GCMs

IPCC SRES A1B, 2080-2099 minus 2000-2019, JJA

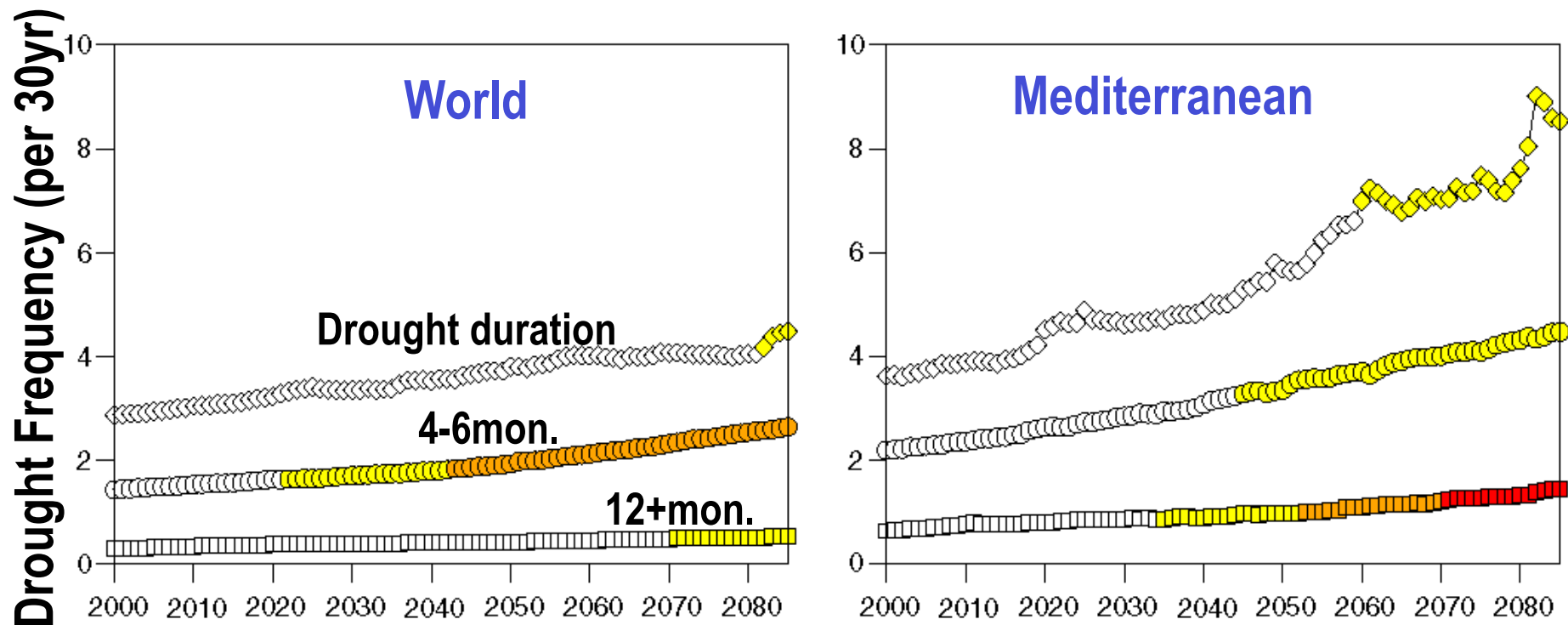


Red = Drying in 2080-2099

PDSI based on IPCC AR4 Model Predicted Temp. and Precip under A1B Scenario



Drought Frequency under SRES A2 Scenario

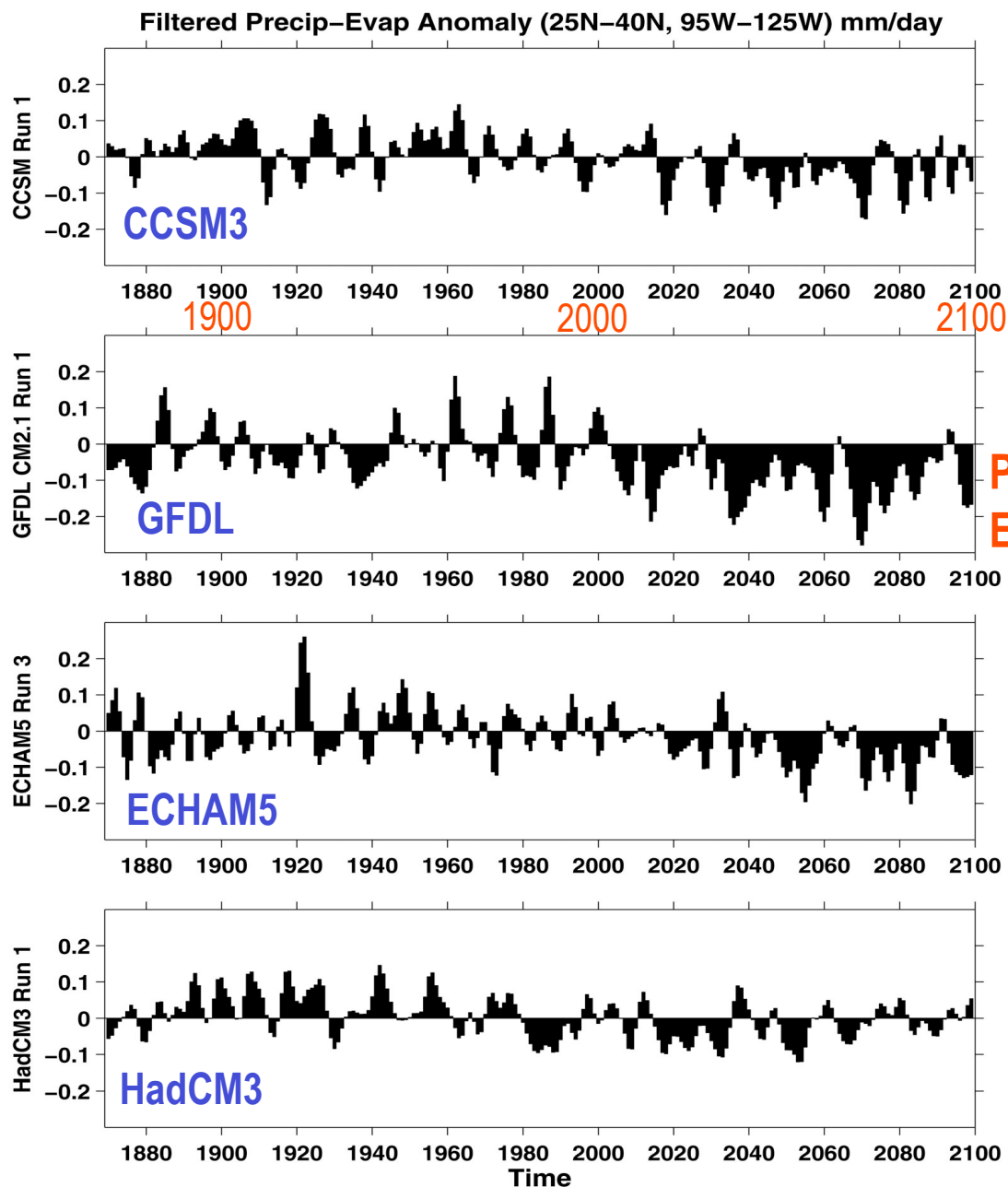


(Sheffield and Wood 2008)

Model Simulated P - E over the Southwest U.S.



NCAR



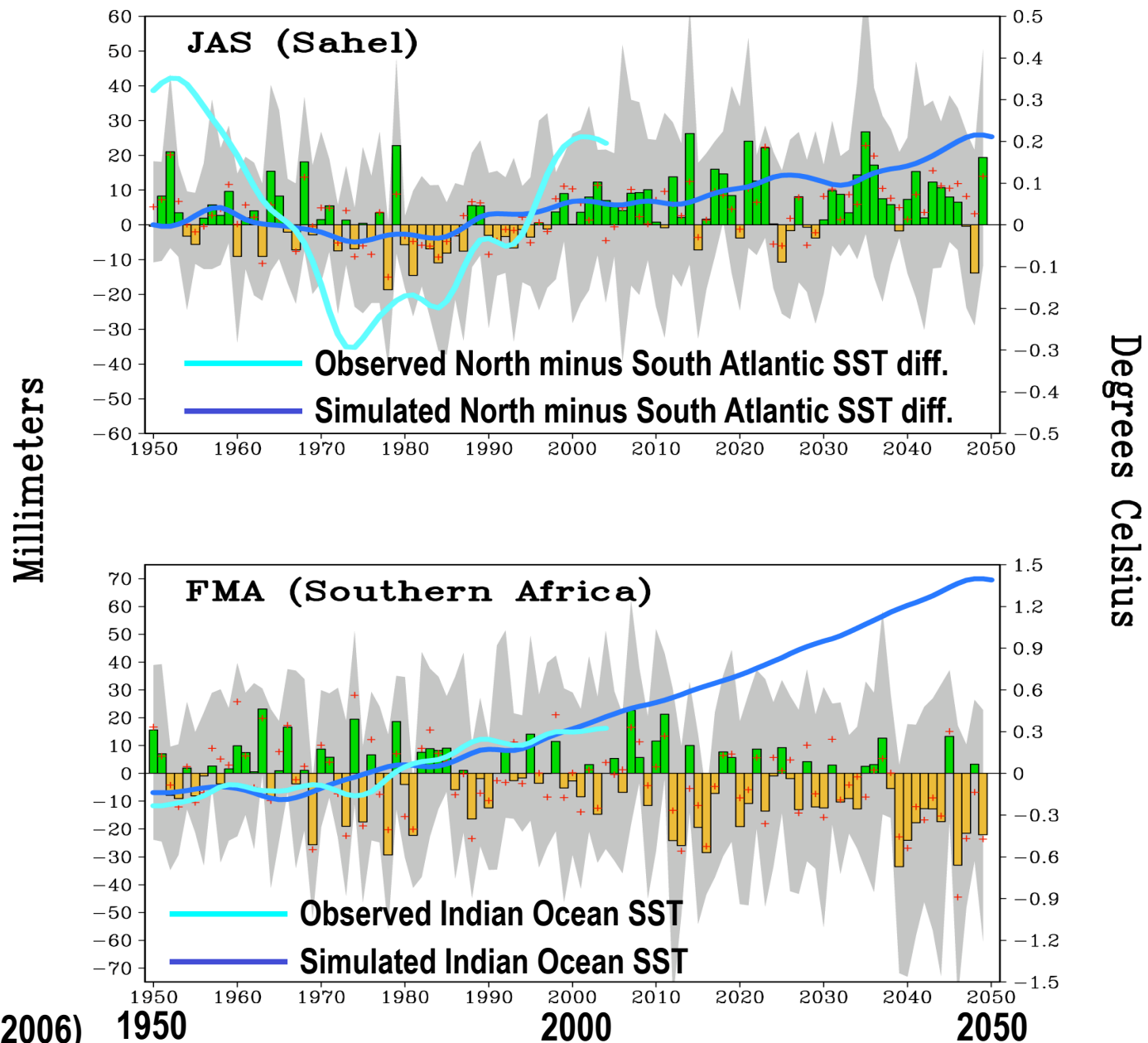
Partly due to poleward
Expansion of the Hadley Cell

Seager et al.'07, *Science*

Projected African Rainfall & SST by 18 Coupled GCMs



NCAR



(Hoerling et al. 2006)

Summary



- Tropical (La Niña-like) SST anomalies likely caused the “Dust Bowl” drought over the U.S. in the 1930s, with amplification by increased dust loading.
- Warming in the South relative to the North Atlantic was a major cause for the Sahel drought, while the warming in the Indian Ocean contributed to the drought in southern Africa.
- Severe droughts similar to the Dust Bowl drought and recent Sahel drought occurred at other times during the last several centuries.
- There appears to be a drying trend over global land from 1950-2008, mostly in Africa, South and East Asia, eastern Australia and the Mediterranean region.
- Changes in precipitation (especially those associated with ENSO) contributed to much of the drying over Africa, Australia, and South Asia; but warming since the 1980s appears to have enhanced the drying at mid- to high-latitudes.
- Climate models predict drying over the subtropics, including the Southwest U.S. and southern Africa, but increased precipitation over West Africa in the 21st century.